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**PREPARATION and EVALUATION
of
FIBER METAL NICKEL BATTERY PLAQUES**

FIRST QUARTERLY PROGRESS REPORT

August 1, to October 31, 1964

by

J. L. Bidler and J. I. Fisher

prepared for

NATIONAL AERONAUTICS and SPACE ADMINISTRATION

CONTRACT NAS 3-6006

HUYCK METALS

A DEPARTMENT OF HUYCK CORPORATION

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I. SUMMARY

Microscopic size measurements of two grades of nickel fiber have been made and the mean, median, range, and standard deviation calculated for length and diameter. Photomicrographs of typical particles, cross sectional areas, and as sintered surfaces have been obtained for both grades of nickel fiber and carbonyl nickel powder. The length spectrum of nickel fibers ranges from submicroscopic to approximately 1500 microns; the apparent diameter ranges from submicroscopic to approximately 50 microns.

The pore size distribution of two grades of sintered metal fibers and carbonyl nickel powder as a function of sintering temperature are presented, as is the effect of a rolling compaction of fiber metal upon the pore size distribution. In general the pore size distribution of sintered carbonyl nickel powder varies little with sintering temperature. The median pore size, which is at the low end of the 10 to 50 micron range, increases slightly as the sintering temperature is increased from 1600°F to 2000°F.

The pore size distribution of sintered nickel fiber is also quite independent of sintering temperature. The median pore size is at the high end of the 10 to 50 micron range. A rolling compaction, which increased the density from 11% to 14% of theoretical, significantly increased the volume of voids in the 10 to 50 micron range and decreased the median pore size 5 to 10 microns.

A study of the effect of sintering temperature upon the density of two grades of nickel fiber and carbonyl nickel powder indicates that the density of carbonyl nickel powder increases rapidly at temperatures above 1600°F while the density of nickel fiber increases slightly from 1600°F to 2150°F.

The relative insensitivity of density and pore size distribution to sintering temperature indicates that internal surface area, electrical conductivity, and strength measurements will dictate the sintering parameters to be used to obtain optimum plaque characteristics.

II. INTRODUCTION

1. Objectives

The primary objective of this program is the development of fiber metal nickel battery plaques having minimum apparent density and maximum internal surface area, electrical conductivity, strength, and flexibility. The inherent advantages of using fiber metal for this application are:

- a. High degree of porosity obtainable.
- b. Controllability of pore size and pore size distribution.
- c. Large surface area of fibers.
- d. Maximum interconnected porosity.
- e. High strength at high porosity.
- f. Formability after sintering.

2. Program Outline

The program outline defines four major tasks, A-D, which are summarized as follows:

Task A. Raw Material Classification

Each raw material used in the program is to be characterized as to particle shape, size, and size distribution. Microscopic measurements of fiber length and diameter are to be supplemented by photomicrographs of as sintered surfaces, cross sectional areas, and shadographs of typical fibers to present both a statistical and a visual description.

Task B. Sintering Study

It is desired to establish the highest sintering temperature that will produce an acceptable amount of shrinkage when the sintering time is held constant at 20 minutes. This information will be used in conjunction with internal surface area, electrical conductivity, and strength measurements to arrive at optimum plaque characteristics.

Task C. Plaque Classification

Plaque classification will include both physical and mechanical testing. Resistivity, internal surface area, density, pore size distribution, mechanical strength, and flexibility will be determined. These data will be used to determine optimum processing parameters and will be compiled for each final configuration plaque made.

Task D. Specimen Samples

A sample of each test plaque on which the classification tests were performed shall be provided to the NASA Project Manager.

III. EXPERIMENTAL APPARATUS and PROCEDURES

A. Microscopic Determination of fiber length and diameter.

1. Apparatus

Leitz Metallux microscope with micrometer stage and graduated eyepiece.

2. Procedure

Microscopic slides of AX1 and AX2 nickel fibers were prepared by suspending a typical sample of fibers in a 1% solution of Carbopol in water. A sample drop of this solution, containing several hundreds of fibers, was placed between two glass slides. The slide was mounted on the micrometer stage, indexed, and viewed through the graduated eyepiece. A magnification of 100X was used for length measurements and 200X for diameter measurements.

To facilitate measurements, length class intervals were defined as 25 microns and diameter class intervals as 2.5 microns. The length and diameter of each fiber was estimated to the appropriate class interval. Duplicate samples were prepared and measured to determine the reproducibility of the technique. The resulting data were tabulated and typical histograms of percent total length versus class interval were prepared.

B. Porosimetry Measurements

1. Apparatus

Aminco Winslow mercury intrusion porosimeter with 0.2 cm^3 penetrometer.

2. Procedure

Volume mercury intruded versus absolute pressure data were obtained for AX1 and AX2 nickel fiber and carbonyl nickel powder sintered in the temperature range from 1600°F to 2150°F. All samples were measured in the as sintered condition. AX1 samples sintered at 1600°F and 2000°F were also measured after a rolling reduction of approximately 25% to show the effect of rolling and surface condition on pore size distribution.

C. Photomicrographs

1. Apparatus

Leitz Metallux microscope with Polaroid camera attachments.

2. Procedure

Low magnification (15X) photographs were taken of as sintered surfaces of AX1 and AX2 nickel fiber sintered at 2000°F and carbonyl nickel powder sintered at 1600°F.

Metallographic mounts were made of the above samples by vacuum impregnating them with a catalyzed epoxy resin. Photomicrographs were taken parallel to the felting plane at a magnification of 210X.

Shadographs of AX1 and AX2 nickel fiber and carbonyl nickel powder were obtained at a magnification of 57X to permit a visual comparison of the three primary raw materials.

D. Sintering Study

1. Apparatus

Lindberg retort furnace with a 12 x 26 x 8 inch hot zone capable of 2150°F with a dry hydrogen atmosphere.

Burrell laboratory furnace with a 2 inch diameter by 15 inch long hot zone capable of 2150°F with a dry hydrogen atmosphere.

2. Procedure

Sample felts both 1 x 3 and 6 x 6 inches were sintered for 20 minutes in dry hydrogen in the temperature range from 1600°F to 2150°F. After sintering, density calculations were made from the weight and volume of the felts.

IV. EXPERIMENTAL RESULTS and DISCUSSION

Task A. Raw Material Classification

A. Fiber Measurements

Frequency tabulations, given in Tables I through VII in the Appendix, were compiled for each determination of fiber length and diameter. The mean, median, range, and standard deviation for AX1 and AX2 nickel fiber were calculated⁽¹⁾ and are summarized in Table VIII.

The mean and median apparent diameter shown are more probably a width measurement due to the fibers settling with the widest lateral dimensions normal to the viewing plane⁽²⁾. Photomicrographs of cross sectional areas, Figures 1, 2 and 3 and shadographs of typical fibers, Figures 4, 5 and 6 also indicate that the shape of the fibers is quite irregular in contrast to the powder particles which are more regular in cross section and have much lower (not measured) l/d ratio.

It is evident from the above that a precise geometrical description of the fibers employed in this program is not possible. The microscopic measurements supplemented by the photomicrographs and shadographs do afford an overall description of the fibers and of the difference between AX1 and AX2 fibers.

A test for significant difference between two standard deviations, the F test⁽³⁾, was made of the duplicate determinations of fiber length and diameter. The results show that there is no significant difference at the 5% level of significance. This is an indication that the counting procedure is reproducible and that the resulting frequency distributions are typical of the entire population.

Frequency distribution histograms showing percent of total measurement versus class interval are shown in Figures 7 and 8 for AX2 nickel fiber length and diameter respectively. These histograms are typical of those for the other materials, in that the histogram shapes are similar in all cases.

(1) Superscripts refer to similarly numbered entries in the Bibliography.

TABLE VIII

Summary of Frequency Tabulation Data

Material	Diameter - Microns				Length - Microns			
	Mean	Median	Standard Deviation	Range	Mean	Median	Standard Deviation	Range
AX1	11.2	5-7.5	.10.3	1-50	139	88-112	163	13-1500
AX2	14.9	10-12.5	11.5	1-50	159	88-112	178	13-1500
Carbonyl Nickel*		2.9-3.6						

*Data obtained from International Nickel Company.

The major significant difference between AX1 and AX2 nickel fiber is the apparent diameter. As shown above the mean diameter of AX2 nickel fiber is approximately 30% larger than that of AX1 fiber.



Fig. 1 Photomicrograph of AX1 Nickel
fiber sintered plaque. 11% Dense.
Section is parallel to felting
plane X210



Fig. 2 Photomicrograph of AX2 Nickel
fiber sintered plaque. 12% Dense.
Section is parallel to felting
plane X210



Fig. 3 Photomicrograph of Carbonyl Nickel
powder sintered plaque. 18% Dense.
X210

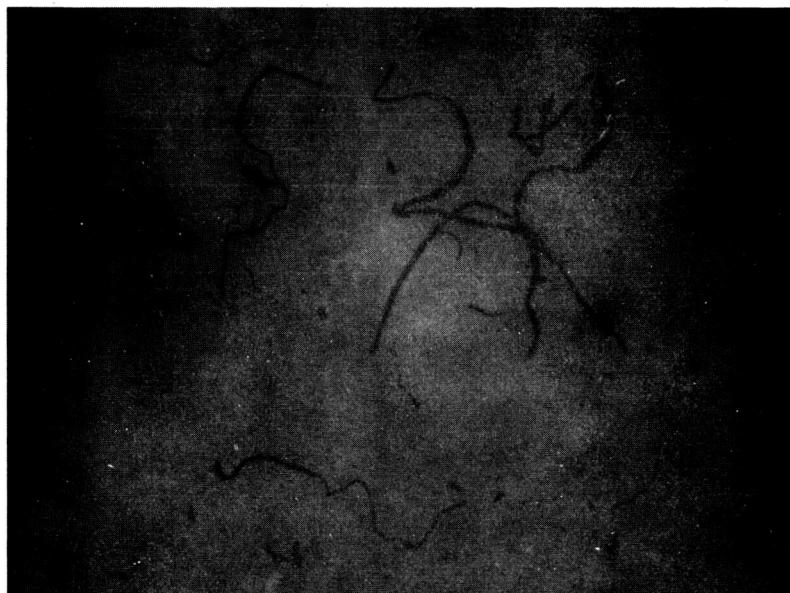


Fig. 4 Shadograph of AX1 Nickel fiber.
X57



Fig. 5 Shadograph of AX2 Nickel fiber.
X57

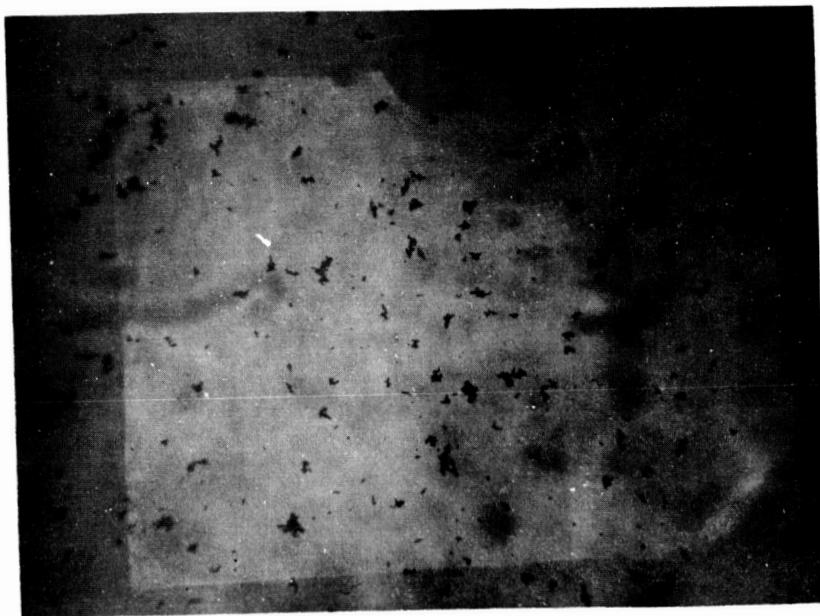


Fig. 6 Shadograph of Carbonyl Nickel powder.
X57

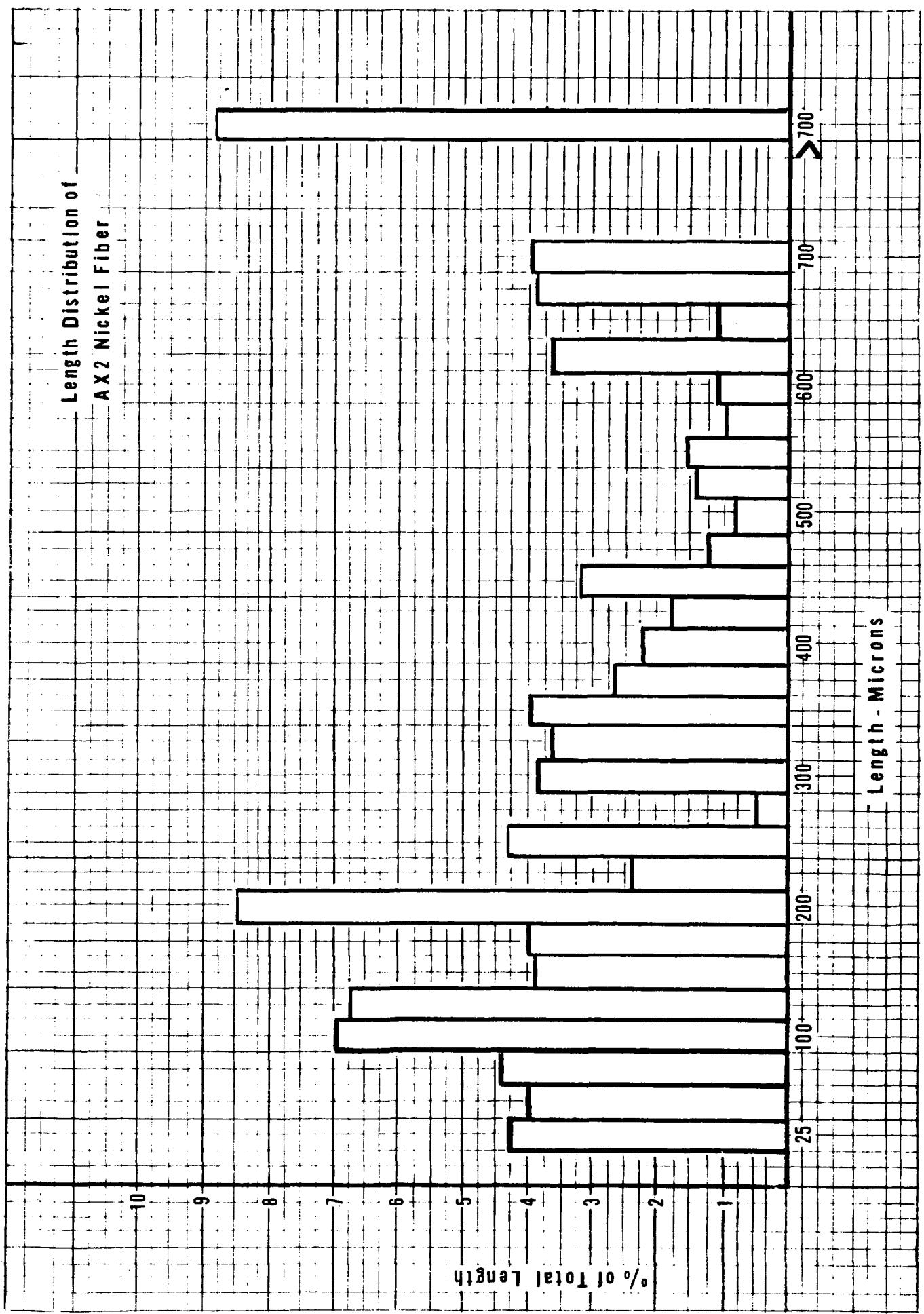


FIG. 7

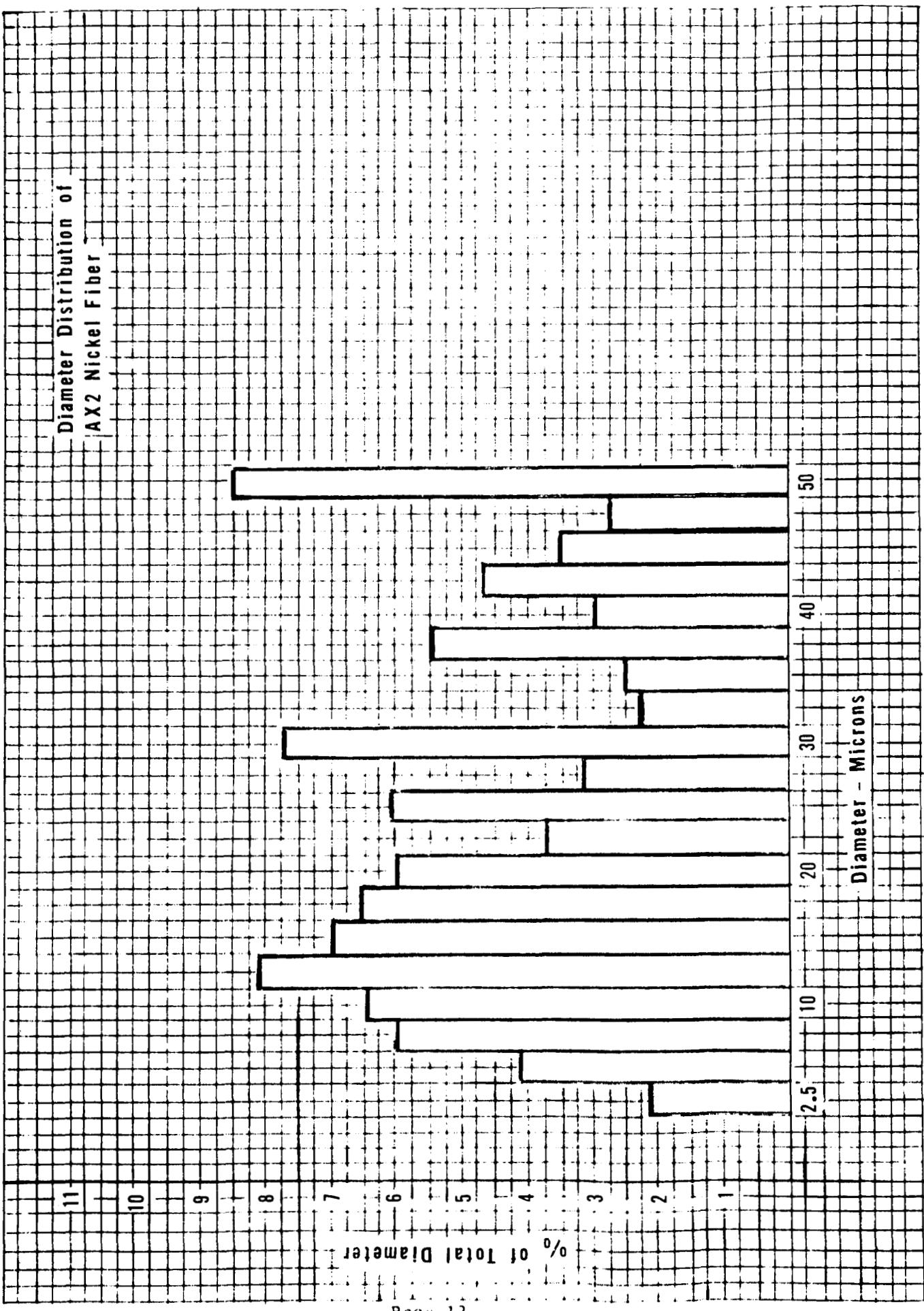


FIG. 8

B. Porosimetry Measurements

Porosimetry data as a function of material and sintering temperature are summarized in Table IX.

It is apparent that there are few closed pores in any of the samples and that increasing sintering temperature tends to develop larger pores. Table X, a tabulation of the percentage of void volume due to pores 10 to 50 microns in diameter, shows that all samples have an appreciable proportion of porosity in the desired range. In the case of fibers, this proportion may be increased significantly by a rolling operation.

Task B. Sintering Study

The effect of sintering temperature at constant time upon the density of AX1 and AX2 nickel fiber and carbonyl nickel powder is shown in Figure 9.

The density of fiber metal is increased only slightly over the entire temperature range investigated. The results of this sintering study and the porosimetry data indicate that the sintering temperature has a relatively small effect upon the density and pore size of fiber metal. Consequently; the results of internal surface area, electrical conductivity, and strength measurements will dictate the sintering parameters to be used.

Photographs (15X) of as sintered surfaces of nickel fiber metal and carbonyl nickel powder are shown in Figures 10, 11, and 12.

TABLE IX

Porosimetry Data for AX1 and AX2 Nickel Fiber and Carbonyl Nickel Powder Sintered at Various Temperatures

Fiber Metal	Sintering Temp. °F	As Sintered						
		A	B	C	D	E	F	G
AX1 Nickel	1600	.180	.024	.154	86.7	85.6	98.7	38.9
	1800	.164	.026	.135	84.1	82.3	97.8	37.2
	2000	.155	.022	.130	85.8	83.9	97.7	47.3
	2150	.170	.025	.140	85.3	82.4	96.6	47.3
AX2 Nickel	1600	.168	.023	.144	86.3	85.7	99.3	47.9
	1800	.152	.022	.129	85.5	84.9	99.2	51.5
	2000	.166	.026	.137	84.3	82.5	97.8	43.8
	2150	.149	.024	.122	83.9	81.9	97.6	52.2
Powder Metal								
Carbonyl Ni	1600	.201	.038	.162	81.0	80.6	99.3	10.0
	2000	.222	.056	.164	74.8	73.9	98.8	15.9
Fiber Metal	As Rolled							
AX1 Nickel	1600	.201	.032	.164	84.1	81.6	97.0	34.3
	2000	.200	.032	.165	84.0	82.5	98.2	40.7

- A. Sample vol., cc = wt. of mercury displaced by sample at 1.75 psia⁽¹⁾
÷ sp. gravity of mercury.
- B. Metal vol., cc = wt. of sample ÷ sp. gravity of metal.
- C. Mercury intrusion volume, cc = vol. of mercury forced into 1.75
psia and 175 psia⁽²⁾.
- D. Total pore volume, % of sample vol.:
100(A-B)/A.
- E. Available pore volume (larger than 1 micron), % of sample vol.:
100(C)/A.
- F. Available pore volume (larger than 1 micron), % of total pore vol.:
100C/(A-B).
- G. Median pore size, microns = measured pore diameter at 50% of total
mercury intrusion vol.

(1) Only pores larger than 100 microns are intruded by mercury at 1.75 psi

(2) Only pores larger than 1 micron are intruded by mercury at 175 psi

TABLE X

Tabulation of Percent of Void Volume due to
Pores 10 to 50 Microns in Diameter

Material	Sintering Temp. °F	A	B	C	D	E	F	
AX1 Ni	1600	10.0	0.154	0.214	0.106	49.5	68.9	
	2000	10.7	0.130	0.183	0.072	39.3	55.4	
AX2 Ni	1600	10.4	0.144	0.198	0.073	36.9	50.7	
	2000	12.3	0.137	0.185	0.077	41.6	56.2	
Carbonyl Ni	1600	17.5	0.162	0.185	0.080	43.2	49.3	
	2000	22.6	0.164	0.192	0.100	52.0	60.9	
AX1 Ni Roll Reduced by 25%	1600	14.2	0.164	0.193	0.144	74.6	87.8	
	2000	14.1	0.165	0.195	0.155	59.0	70.0	

A = Density, % of theoretical

B = Total intruded porosity, cm³ (1)C = Total porosity of sample, cm³

D = Volume of pores between 10 and 50 microns

E = Pore volume due to 10 to 50 micron pores, % of total volume

F = Pore volume due to 10 to 50 micron pores, % of total intruded volume.

(1) Volume of pores 1 to 100 microns in diameter.

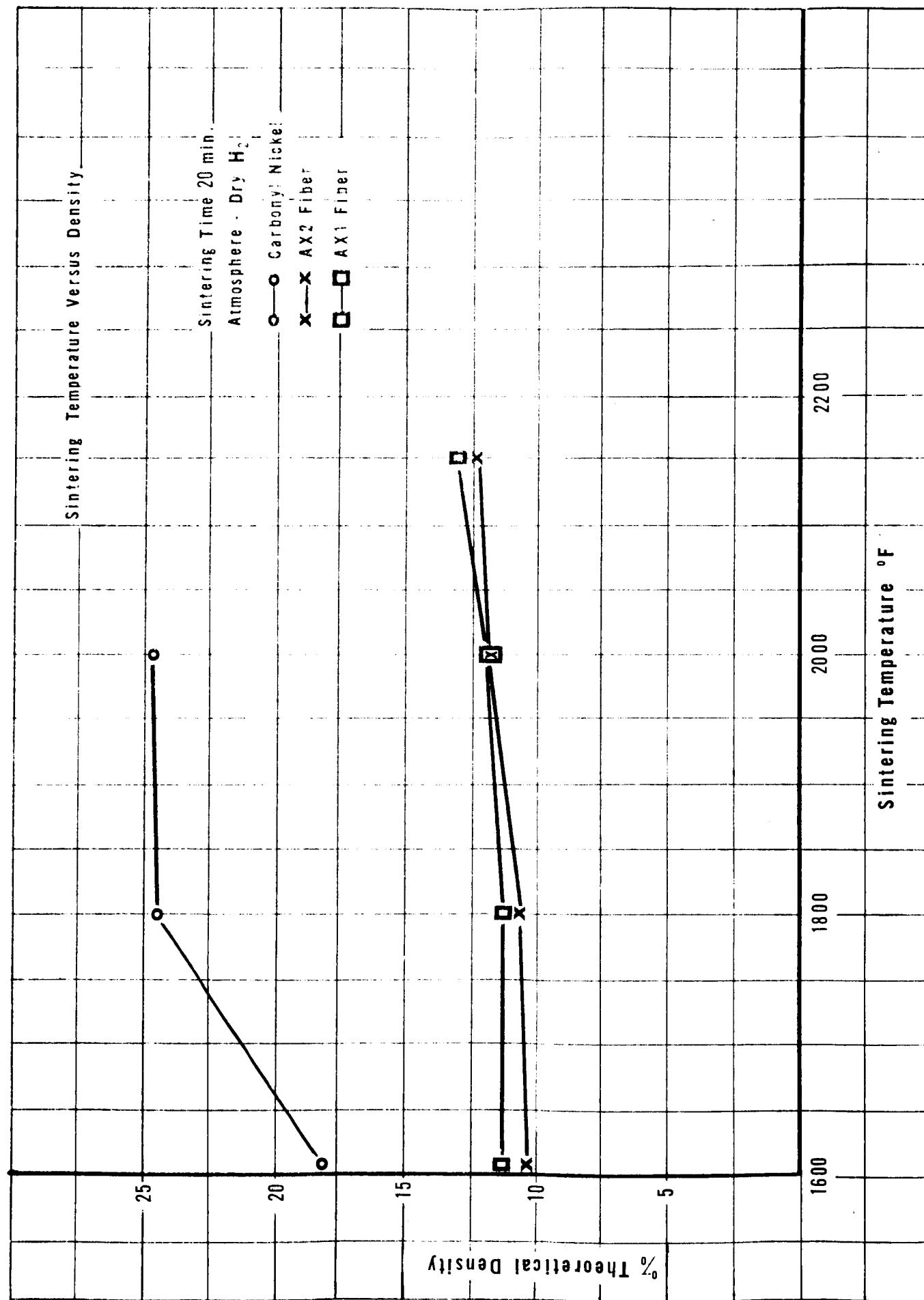


FIG. 9



Fig.10 Photograph of as-sintered surface
of AX1 Nickel fiber. X15

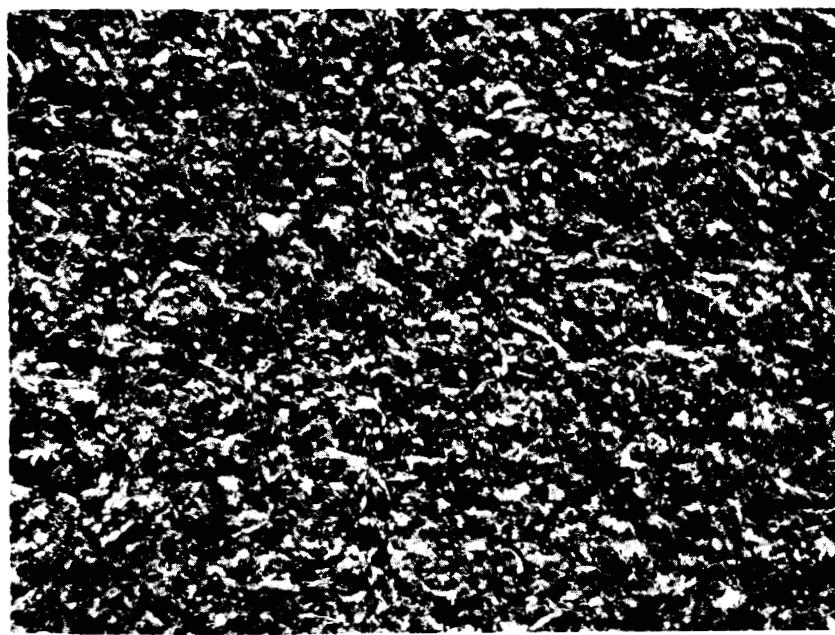


Fig.11 Photograph of as-sintered surface
of AX2 Nickel fiber. X15

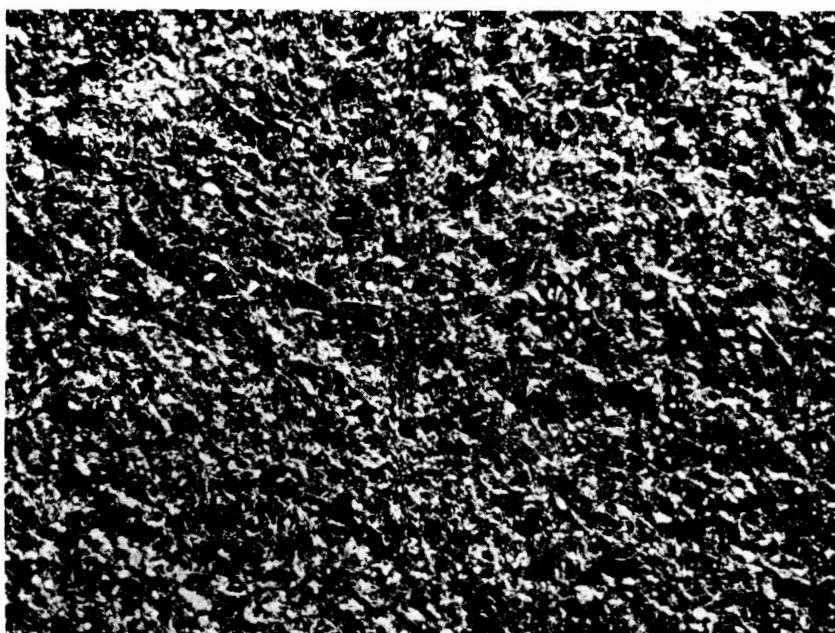


Fig.10 Photograph of as-sintered surface
of AX1 Nickel fiber. X15

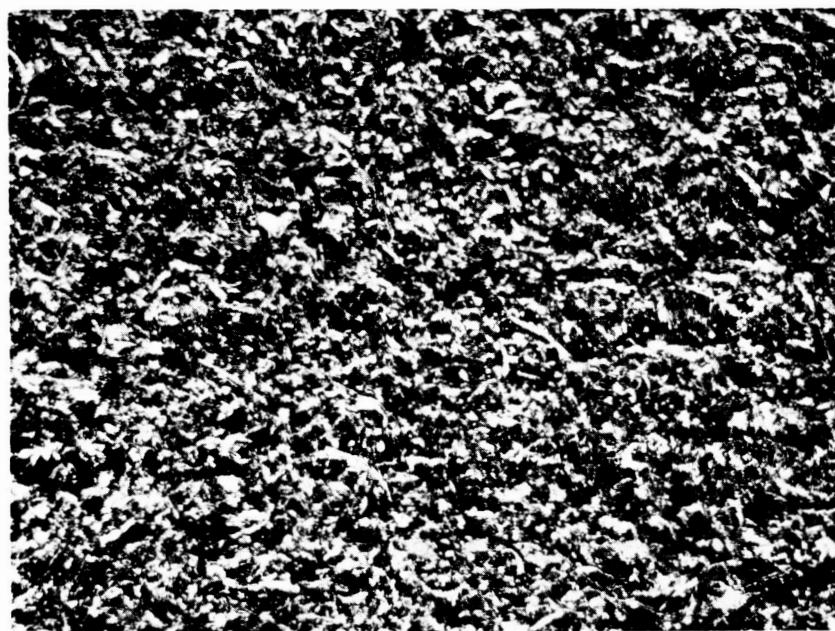


Fig.11 Photograph of as-sintered surface
of AX2 Nickel fiber. X15

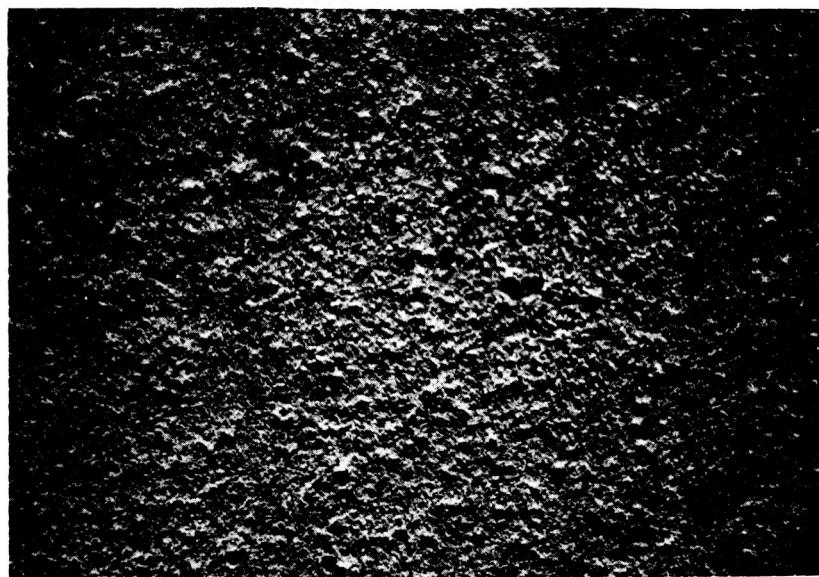


Fig. 12 Photograph of as-sintered surface
of Carbonyl Nickel powder. X15

V. FUTURE WORK

Work during the next reporting period will be directed primarily at obtaining internal surface area, electrical conductivity, and strength measurements, for all three primary raw materials, as a function of sintering temperature.

VI. BIBLIOGRAPHY

- (1) Edward C. Bryant - STATISTICAL ANALYSIS Chapter 4.
McGraw-Hill Book Company, Inc., New York, 1960

- (2) Clyde Orr, Jr.-J. M. Dallavalle -
FINE PARTICLE MEASUREMENT pp 14-42.
The MacMillan Company, New York, 1960.

- (3) George E. Dieter, Jr. - MECHANICAL METALLURGY p 443.
McGraw-Hill Book Company, Inc., New York, 1961.

VII. GLOSSARY

1. Type A fiber - Fiber produced by a proprietary process ranging in mean diameter from 3 to 30 microns.
2. Type B fiber - Fiber derived from metal wool.
3. Type C fiber - Fiber derived from metal wire.
4. Fiber grade - Generally defines the fiber diameter. Since in type A and B the diameter is not constant, the grade designation is preferred to a mean diameter designation.
5. Fiber type and grade

To avoid cumbersome discussions the type and grade of fiber used in a given specimen will be reduced to such terminology as AX1, meaning type A fiber Grade X1.

VIII. APPENDIX

Frequency Tabulations.

LIST of SYMBOLS

F = Frequency

X = Class Midpoint

N = Number of Samples

SD = Standard Deviation

$$\text{Mean} = \frac{\sum FX}{N} = \bar{X}$$

Median = Value of $\frac{N^{\text{th}}}{2}$ sample

$$SD = \sqrt{\frac{\sum_{i=1}^N (X_i - \bar{X})^2}{N-1}}$$

TABLE I

Frequency Tabulation of Fiber Length of AXI Nickel Fiber

Sample 1

Length Class Interval Microns	Class Midpoint X	Frequency F	FX	FX % of Total	X ²	FX ²
13-37	25	228	5700	2.9	625	142500
38-62	50	193	9650	4.9	2500	482500
63-87	75	111	8325	4.2	5625	624375
88-112	100	135	13500	6.9	10000	1350000
113-137	125	143	17875	9.1	15625	2234375
138-162	150	74	11100	5.6	22500	1665000
163-187	175	62	12950	6.6	30625	1898750
188-212	200	74	14800	7.5	40000	2960000
213-237	225	35	7875	4.0	50625	1771875
238-262	250	28	7000	3.6	62500	1750000
263-287	275	18	4950	2.5	75625	1361250
288-312	300	35	10500	5.3	90000	3150000
313-337	325	12	3900	2.0	105625	1267500
338-362	350	15	5250	2.7	122500	1837500
363-387	375	12	4500	2.3	140625	1687500
388-412	400	16	6400	3.3	160000	2560000
413-437	425	8	3400	1.7	180625	1445000
438-462	450	9	4050	2.1	202500	1822500
463-487	475	10	4750	2.4	225625	2256250
488-512	500	11	5500	2.8	250000	2750000
513-537	525	4	2100	1.1	275625	1102500
538-562	550	5	2750	1.4	302500	1512500
563-587	575	3	1725	0.9	330625	991875
588-612	600	3	1800	0.9	360000	1800000
613-637	625	4	2500	1.3	390625	1562500
638-662	650	5	3250	1.7	422500	2112500
663-687	675	5	3375	1.7	455625	2278125
688-712	700	11	7700	3.9	490000	5390000
788-812	800	2	1600	0.8	640000	1280000
888-912	900	2	1800	0.9	810000	1620000
988-1012	1000	2	2000	1.0	1000000	2000000
1188-1212	1200	1	1200	0.6	1440000	1440000
1288-1312	1300	1	1300	0.7	1690000	1690000
1488-1512	1500	1	1500	0.8	2250000	2250000

Mean 154

Median 88-112

Standard

Deviation 158

TABLE II

Frequency Tabulation of Fiber Length of AX1 Nickel Fiber

Sample 2						
Length Class Interval Microns	Class Midpoint X	Frequency F	FX	FX % of Total	X ²	FX ²
13-37	25	312	7800	6.0	625	195000
38-62	50	151	7550	5.8	2500	377500
63-87	75	96	7200	5.5	5625	540000
88-112	100	151	15100	11.6	10000	1510000
113-137	125	72	9000	6.9	15625	1125000
138-162	150	41	6150	4.7	22500	922500
163-187	175	22	3850	3.0	30625	673750
188-212	200	38	7600	5.8	40000	1520000
213-237	225	23	5175	4.0	50625	1164375
238-262	250	12	3000	2.3	62500	750000
263-287	275	7	1925	1.5	75625	529375
288-312	300	21	6300	4.8	90000	1890000
313-337	325	6	1950	1.5	105625	633750
338-362	350	12	4200	3.2	122500	1470000
363-387	375	6	2250	1.7	140625	843750
388-412	400	8	3200	2.5	160000	1280000
413-437	425	7	2975	2.3	180625	1264375
438-462	450	4	1800	1.4	202500	810000
463-487	475	4	1900	1.4	225625	902500
487-512	500	12	600	0.5	250000	3000000
513-537	525	0	0	0	275625	0
538-562	550	4	2200	1.7	302500	1210000
563-587	575	1	575	0.4	330625	330625
588-612	600	1	600	0.5	360000	360000
613-637	625	2	1250	1.0	390625	781250
638-662	650	10	6500	5.0	422500	4225000
663-687	675	2	1350	1.0	455625	911250
688-712	700	6	4200	3.2	490000	2940000
788-812	750	2	1500	1.1	562500	1125000
888-912	800	3	2400	1.8	640000	1920000
988-1012	900	2	1800	1.4	810000	1620000
1188-1212	1000	5	5000	3.8	1000000	5000000
1188-1212	1200	3	3600	2.8	1440000	4320000

Mean 125

Median 88-112

Standard

Deviation 169

TABLE III

Frequency Tabulation of Fiber Length of AX2 Nickel Fiber

Sample 1

Length Class Interval Microns	Class Midpoint X	Frequency F	FX	FX % of Total	X ²	FX ²
13-37	25	119	2975	4.3	625	74375
38-62	50	56	2800	4.0	2500	140000
63-87	75	41	3075	4.4	5625	230625
88-112	100	49	4900	7.0	10000	490000
113-137	125	38	4750	6.8	15625	593750
138-162	150	18	2700	3.9	22500	405000
163-187	175	16	2800	4.0	30625	490000
188-212	200	30	6000	8.6	40000	1200000
213-237	225	8	1800	2.6	50625	405000
238-262	250	12	3000	4.3	62500	750000
263-287	275	1	275	0.4	75625	75625
288-312	300	9	2700	3.9	90000	810000
313-337	325	8	2600	3.7	105625	845000
338-362	350	8	2800	4.0	122500	980000
363-387	375	5	1875	2.7	140625	703125
388-412	400	4	1600	2.3	160000	640000
413-437	425	3	1275	1.8	180625	541875
438-462	450	5	2250	3.2	202500	1012500
463-487	475	2	950	1.3	225625	445250
488-512	500	1	500	0.7	250000	250000
513-537	525	2	1050	1.5	275625	551250
538-562	550	2	1100	1.6	302500	605000
563-587	575	1	575	0.8	330625	330625
588-612	600	1	600	0.9	360000	360000
613-637	625	4	2500	3.6	390625	1562500
638-662	650	1	650	0.9	422500	422500
663-687	675	4	2700	3.9	455625	1822500
688-712	700	4	2800	4.0	490000	1960000
737-762	750	1	750	1.1	562500	562500
788-812	800	1	800	1.1	640000	640000
813-837	825	1	825	1.2	680625	680625
838-862	850	1	850	1.2	722500	722500
913-937	925	1	925	1.3	855625	855625
988-1012	1000	1	1000	1.4	1000000	1000000
1013-1037	1025	1	1025	1.5	1050625	1050625

Mean 152

Median 88-112

Standard

Deviation 172

TABLE IV

Frequency Tabulation of Fiber Length of AX2 Nickel Fiber

Sample 2

Length Class Interval Microns	Class Midpoint X	Frequency F	FX	FX% of Total	X ²	FX ²
13-37	25	66	1650	2.0	625	41250
38-62	50	85	4250	5.1	2500	212500
63-87	75	56	4200	5.1	5625	315000
88-112	100	65	6500	7.8	10000	650000
113-137	125	46	5750	6.9	15625	718750
138-162	150	29	4350	5.2	22500	652500
163-187	175	8	1400	1.7	30625	245000
188-212	200	28	5600	6.7	40000	1120000
213-237	225	13	2925	3.5	50625	658125
238-262	250	12	3000	3.6	62500	750000
263-287	275	4	1100	1.3	75625	302500
288-312	300	15	4500	5.4	90000	1350000
313-337	325	4	1300	1.6	105625	422500
338-362	350	5	1750	2.1	122500	612500
363-387	375	5	1875	2.3	140625	703125
388-412	400	8	3200	3.9	160000	1280000
413-437	425	5	2125	2.6	180625	903125
438-462	450	6	2700	3.2	202500	1215000
463-487	475	2	950	1.1	225625	451250
488-512	500	10	5000	6.0	250000	2500000
513-537	525	2	1050	1.3	275625	551250
538-562	550	2	1100	1.3	302500	605000
563-587	575	2	1150	1.4	330625	661250
588-612	600	1	600	0.7	360000	360000
613-637	625	0	0	0	390625	0
638-662	650	1	650	0.8	422500	422500
663-687	675	0	0	0	455625	0
688-712	700	6	4200	5.1	490000	2940000
738-762	750	2	1500	1.8	562500	1125000
788-812	800	2	1600	1.9	640000	1280000
888-912	900	1	900	1.1	810000	810000
988-1012	1000	2	2000	2.4	1000000	2000000
1238-1262	1250	1	1250	1.5	1562500	1562500
1338-1362	1350	1	1350	1.6	1822500	1822500
1488-1512	1500	1	1500	1.8	2250000	2250000

Mean 167

Median 88-112

Standard

Deviation 183

TABLE V

Frequency Tabulation of Fiber Diameter of AX2 Nickel Fiber

Sample 1

Diameter Class Interval Micron	Class Midpoint X	Frequency F	FX	FX % of Total	X^2	FX^2
1-3.7	2.5	47	117.5	2.2	6	282
3.8-6.2	5.0	44	220.0	4.1	25	1100
6.3-8.7	7.5	43	322.5	6.0	56	2408
8.8-11.2	10.0	34	340.0	6.4	100	3400
11.3-13.7	12.5	35	437.5	8.2	156	5460
13.8-16.2	15.0	25	375.0	7.0	225	5625
16.3-18.7	17.5	20	350.0	6.5	306	6120
18.8-21.2	20.0	16	320.0	6.0	400	6400
21.3-23.7	22.5	9	202.5	3.8	506	4554
23.8-26.2	25.0	13	325.0	6.1	625	8125
26.3-27.5	27.5	6	165.0	3.1	756	4536
28.8-31.2	30.0	14	420.0	7.8	900	12600
31.3-33.7	32.5	4	130.0	2.4	1056	4224
33.8-36.2	35.0	4	140.0	2.6	1225	4900
36.3-38.7	37.5	8	300.0	5.6	1406	11248
38.8-41.2	40.0	4	160.0	3.0	1600	6400
41.3-43.7	42.5	6	255.0	4.8	1806	10836
43.8-46.2	45.0	4	180.0	3.4	2025	8100
46.3-48.7	47.5	3	142.5	2.7	2256	6768
48.8-50	50.0	9	450.0	8.4	2500	22500

Mean 15.4

Median 10.0-12.5

Standard

Deviation 12.4

TABLE VI

Frequency Tabulation of Fiber Diameter of AX2 Nickel Fiber

Sample 2

Diameter Class Interval Micron	Class Midpoint X	Frequency F	FX	FX % of Total	X^2	FX^2
1-3.7	2.5	69	172.5	2.8	6	431
3.8-6.2	5.0	48	240.0	3.9	25	1200
6.3-8.7	7.5	54	405.0	6.6	56	3024
8.8-11.2	10.0	48	480.0	7.9	100	4800
11.3-13.7	12.5	29	362.5	5.9	156	4524
13.8-16.2	15.0	31	465.0	7.6	225	6975
16.3-18.7	17.5	30	525.0	8.6	306	9180
18.8-21.2	20.0	23	460.0	7.5	400	9200
21.3-23.7	22.5	16	360.0	5.9	506	8096
23.8-26.2	25.0	28	700.0	11.5	625	17500
26.3-27.5	27.5	9	247.5	4.1	756	6804
28.8-31.2	30.0	15	450.0	7.4	900	13500
31.3-33.7	32.5	3	97.5	1.6	1056	3168
33.8-36.2	35.0	8	280.0	4.6	1225	9800
36.3-38.7	37.5	6	225.0	3.7	1406	8436
38.8-41.2	40.0	3	120.0	2.0	1600	4800
41.3-43.7	42.5	3	127.5	2.1	1806	5418
43.8-46.2	45.0	3	135.0	2.2	2025	6075
46.3-48.7	47.5	1	47.5	0.8	2256	2256
48.8-50	50.0	4	200.0	3.3	2500	10000

Mean 14.1

Median 10.0-12.5

Standard

Deviation 11.4

TABLE VII

Frequency Tabulation of Fiber Diameter of AX1 Nickel Fiber

Sample 1

Diameter Class Interval Micron	Class Midpoint X	Frequency F	FX	FX % of Total	X ²	FX ²
1-3.7	2.5	164	410.0	5.8	6	984
3.8-6.2	5.0	99	495.0	7.0	25	2475
6.3-8.7	7.5	74	555.0	7.8	56	4144
8.8-11.2	10.0	80	800.0	11.3	100	8000
11.3-13.7	12.5	51	637.5	9.0	156	7956
13.8-16.2	15.0	23	345.0	4.9	225	5175
16.3-18.7	17.5	26	455.0	6.4	306	7956
18.8-21.2	20.0	17	340.0	4.8	400	6800
21.3-23.7	22.5	18	405.0	5.7	506	9108
23.8-26.2	25.0	30	750.0	10.6	625	18750
26.3-28.7	27.5	3	82.5	1.2	756	2268
28.8-31.2	30.0	12	360.0	5.1	900	10800
31.3-33.7	32.5	4	130.0	1.8	1056	4224
33.8-36.2	35.0	7	245.0	3.4	1225	8575
36.3-38.7	37.5	7	262.5	3.7	1406	9842
38.8-41.2	40.0	1	40.0	0.6	1600	1600
41.3-43.7	42.5	1	42.5	0.6	1806	1806
43.8-46.2	45.0	1	45.0	0.6	2025	2025
46.3-48.7	47.5	2	95.0	1.3	2256	4512
48.8-50	50.0	12	600.0	8.4	2500	30000

Mean 11.2

Median 5.0-7.5

Standard

Deviation 10.3